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PROPOSED LM POWERED-DESCENT TRAJECTORY FOR THE APOLLO LUNAR LANDING MISSION

By Willis M. Bolt and Floyd V. Bennett
Rendezvous Analysis Branch

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MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
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PROJECT APOLLO

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FIGURES

Figure		Page
1	LM lunar descent total trajectory	
	(a) Range	8
	(b) Altitude	8
	(c) Altitude rate	8
	(d) Horizontal velocity	8
	(e) Total velocity	9
	(f) Flight-path angle	9
	(g) Visibility angle	9
	(h) Pitch angle	9
	(i) Thrust	9
2	Altitude-range profile for LM lunar descent trajectory	11
3	Altitude-range rate profile for LM lunar descent trajectory	12
4	Final approach and landing phases of LM lunar descent	
	(a) Range	14
	(b) Altitude	14
	(c) Altitude rate	14
	(d) Horizontal velocity	14
	(e) Total velocity	15
	(f) Flight-path angle	15
	(g) Visibility angle	15
	(h) Pitch angle	15
	(i) Thrust	15
5	Landing phase trajectory characteristics and constraints	17

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SUMMARY AND INTRODUCTION

A preliminary LM powered-descent trajectory reported in reference 1 has been used for the past year as the nominal descent trajectory for the Apollo lunar landing mission. This trajectory profile was based partly on guidance and targeting developed by MIT/IL and partly on an unguided landing phase which satisfies constraints for pilot control as specified in reference 2. Recently the constraints during the final approach and landing phases were modified as reported in reference 3. Furthermore, a change in the descent initiation (engine ignition) algorithm suggested in reference 4 has recently been incorporated into the MIT/IL guidance logic. Thus, a study was undertaken by MPAD to determine new targeting parameters to provide a complete guided descent maneuver to be compatible with the new constraints and new ignition logic. This study was reported in reference 5. The purpose of this report is to present the trajectory characteristics for a LM powered-descent maneuver selected from the study in reference 5 and propose that this trajectory be used for mission planning studies as the new nominal trajectory for the Apollo lunar landing mission.

DEFINITION OF THE POWERED-DESCENT MANEUVER

Operational Phases

The LM powered-descent trajectory is initiated at pericynthion of a 50 000-ft by 80-n. mi. descent transfer orbit. The powered descent consists of three operational phases - braking, final approach, and landing. The braking phase, initiated at pericynthion, is designed for efficient reduction of the orbital velocity and terminates at a position termed hi-gate, which is at approximately 9000-ft altitude. The final approach phase, beginning at hi-gate, is designed to allow for pilot visual (out-the-window) assessment of the landing area and for abort safety. This phase terminates at a position termed lo-gate, which is at approximately 500-ft altitude. The landing phase, beginning at lo-gate, is designed to provide the crew with detailed visual assessment of the landing area and to provide compatibility for pilot take-over from the automatic control. This phase includes a slow vertical descent from approximately 65 ft and terminates at touchdown on the surface.

Guidance and Targeting

The automatic guidance logic is based on quadratic acceleration for the predominant portion of the descent. During the braking phase the quadratic guidance is targeted to the hi-gate state vector. Linear guidance is used when time-to-go (Tgo) is less than 20 seconds. A short 4-second transition period of linear guidance is used to achieve the desired attitude for beginning the final approach phase. After achieving hi-gate the quadratic guidance is targeted to a state vector for beginning vertical descent. Again, linear guidance is utilized when Tgo approaches 0 (less than 10 seconds) and is utilized for a short 4-second transition to achieve the vertical attitude descent. The guidance for the vertical descent is a velocity nulling technique for maintaining a constant descent rate. A complete description of the descent guidance is given in reference 6.

DESCRIPTION OF PROPOSED TRAJECTORY

The proposed descent trajectory is based on the LM systems and spacecraft characteristics defined in reference 7. The guidance target vectors are given in table I. Time histories of the trajectory characteristics, thrust profile, and guidance commands for the entire descent are given in figure 1. The visibility angle shown in part (c) of figure 1 is the included angle between the X-body axis and the vector from the vehicle to the current landing site. The altitude-range profile for the entire descent is shown in figure 2. The variation of altitude-rate with altitude is illustrated in figure 3 for the entire descent. Enlargements of the time histories of the trajectory characteristics and guidance commands for the final approach and landing phases are illustrated in figure 4.

The constraints for pilot control during the landing phase have been defined in reference 3 as a function of range to the landing site. In figure 5, the characteristics of the proposed trajectory during the landing phase are presented in the same range format for purposes of comparison with the constraints in reference 3. It can be seen from this figure that the trajectory characteristics are within (less than or equal to) the constraint boundaries throughout the descent phase. The time scales represent the time-to-go to the transition to vertical attitude.

The ΔV and propellant requirements for the descent trajectory are tabulated in table II for each operational phase. The total ΔV is 6706 fps which is within the nominal budgeted allowance of reference 8.

CONCLUDING REMARKS

A LM powered-descent trajectory for lunar landing has been presented which satisfies the current operational constraints. It is proposed that this trajectory be used in engineering simulations as the new nominal trajectory for the Apollo lunar landing mission.

TABLE I.- GUIDANCE TARGET VECTORS FOR LM POWERED DESCENT

Aim conditions	Descent phases					
	Ignition	Trim	Braking	Transition to hi-gate	Final approach and landing	Transition to vertical
Position (L-frame[a]):						
X, ft			5 711 987	5 711 347	5 702 472	5 702 460
Y, ft			0	0	0	0
Z, ft	1 559 654		-33 077	-30 892	-1.733	0
Velocity (G-frame[b]):						
X, fps			-159.3	-158.4	-3.1	-3.0
Y, fps			0	0	0	0
Z, fps			561.3	532.6	1.3	0
Acceleration (G-frame[b]):						
X, ft/sec^2			-1.454	1.915	.05	0
Y, ft/sec^2			0	0	0	0
Z, ft/sec^2			-8.301	-6.075	-.65	0
Jerk (G-frame[b]):						
Z, ft/sec^3			-.009829	0	.034336	0
Nominal time for phase, sec		26	467	4	158	4

[a]The L-frame coordinate system has its origin at the center of the moon; the X axis continuously pierces the initial landing site, the Y axis is perpendicular to the LM landing trajectory at the end of the visibility phase, and the Z axis completes the right-hand system.

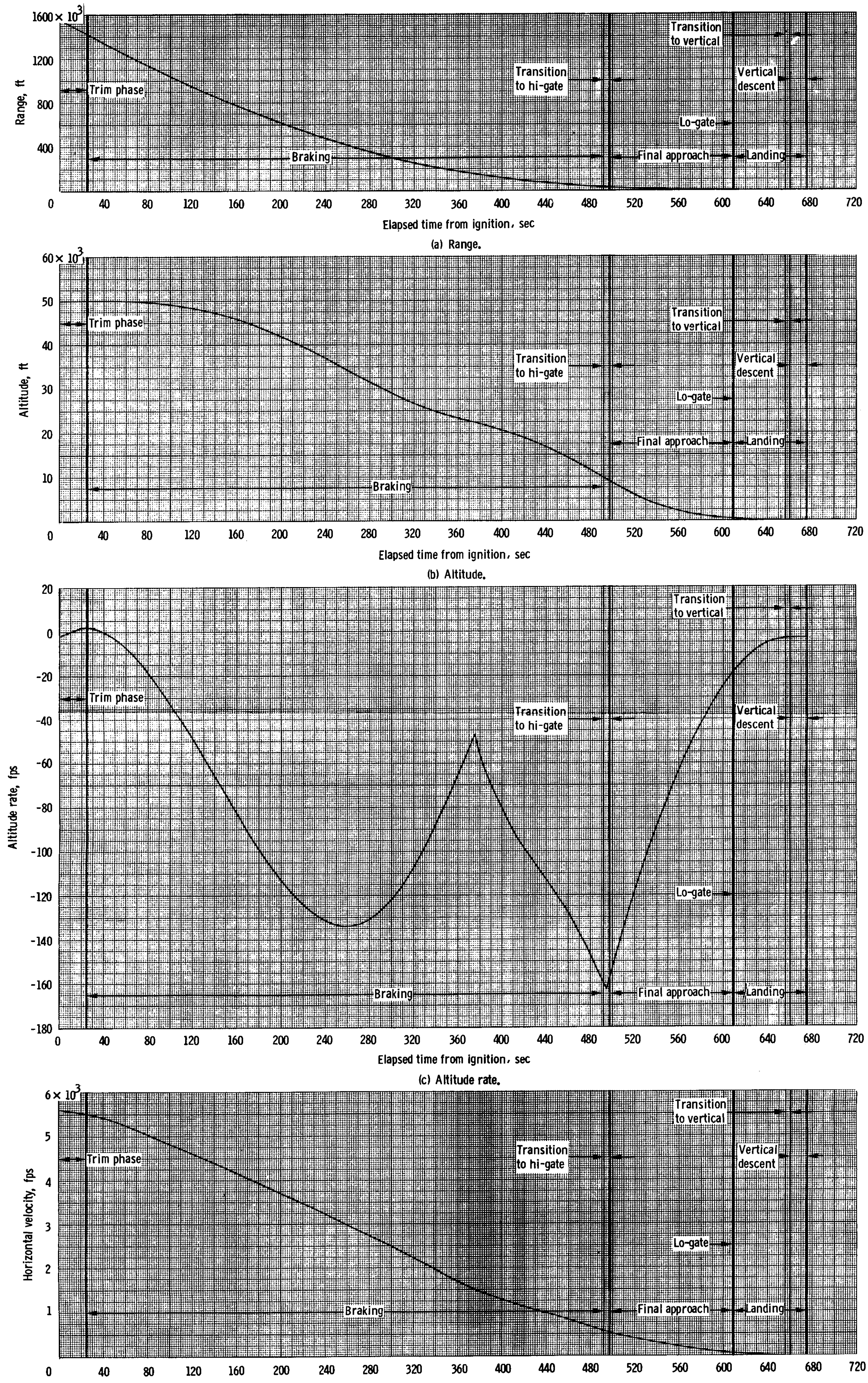
[b]The G-frame coordinate system has its origin at the current landing site; the positive X axis is from the center of the moon to the current landing site, the positive Y axis is normal to the trajectory plane at the time of arrival at the aim point, and the Z axis completes the right-hand system.

TABLE II.- ΔV AND PROPELLANT REQUIRED FOR

NOMINAL LM POWERED DESCENT

[Nominal total ΔV allowed = 6739 fps]

ΔV, fps:	
Braking phase	5 362
Final approach phase	861
Landing phase	305
Vertical descent	81
Total	6 609
Propellant, lb:	
Braking phase	13 817
Final approach phase	1 621
Landing phase	537
Vertical descent	139
Total	16 115



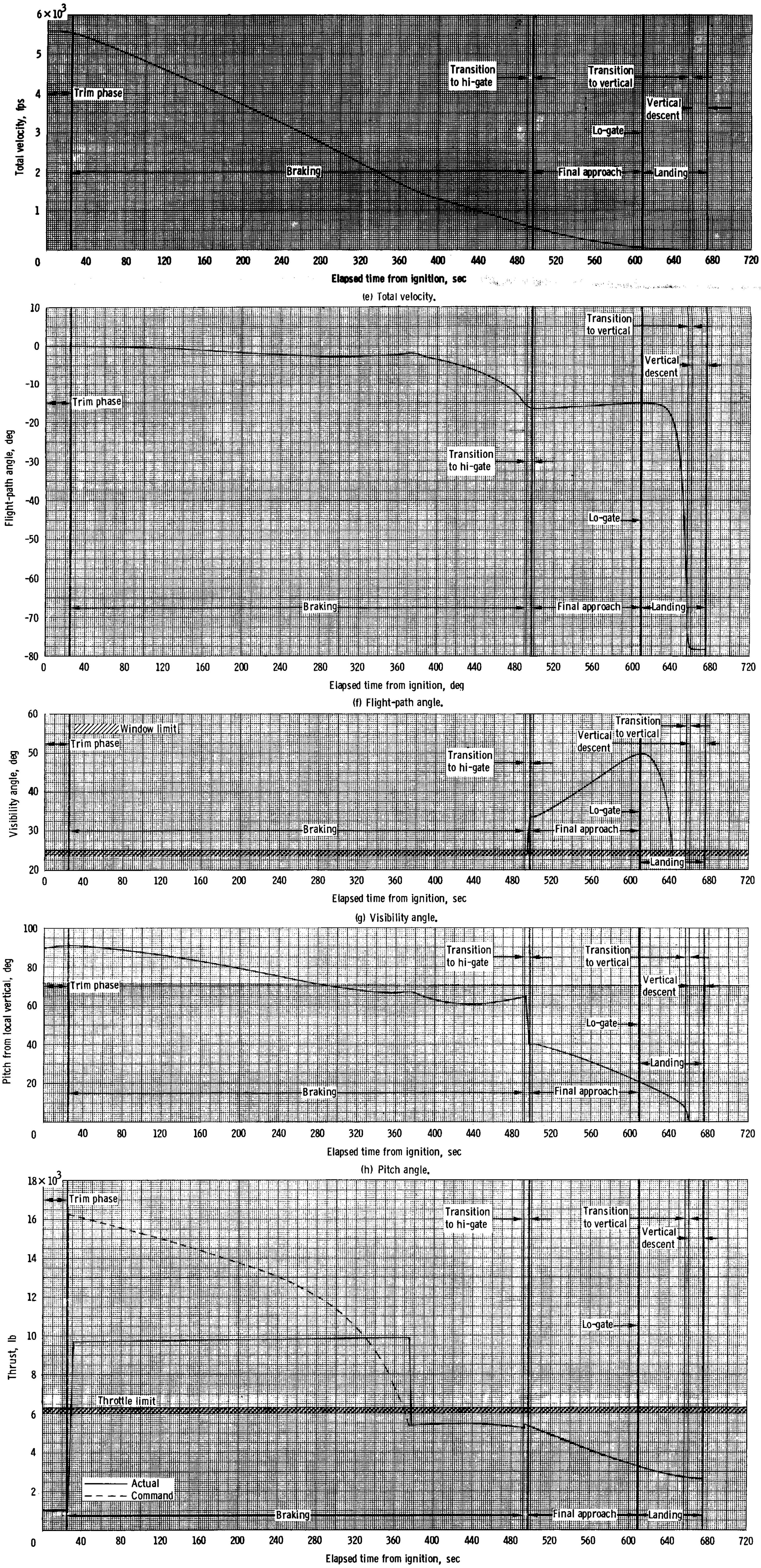
(a) Range.

(b) Altitude.

(c) Altitude rate.

(d) Horizontal velocity.

Figure 1. - LM lunar descent total trajectory.



(e) Total velocity.

(f) Flight-path angle.

(g) Visibility angle.

(h) Pitch angle.

(i) Thrust.

Figure 1. - Concluded.

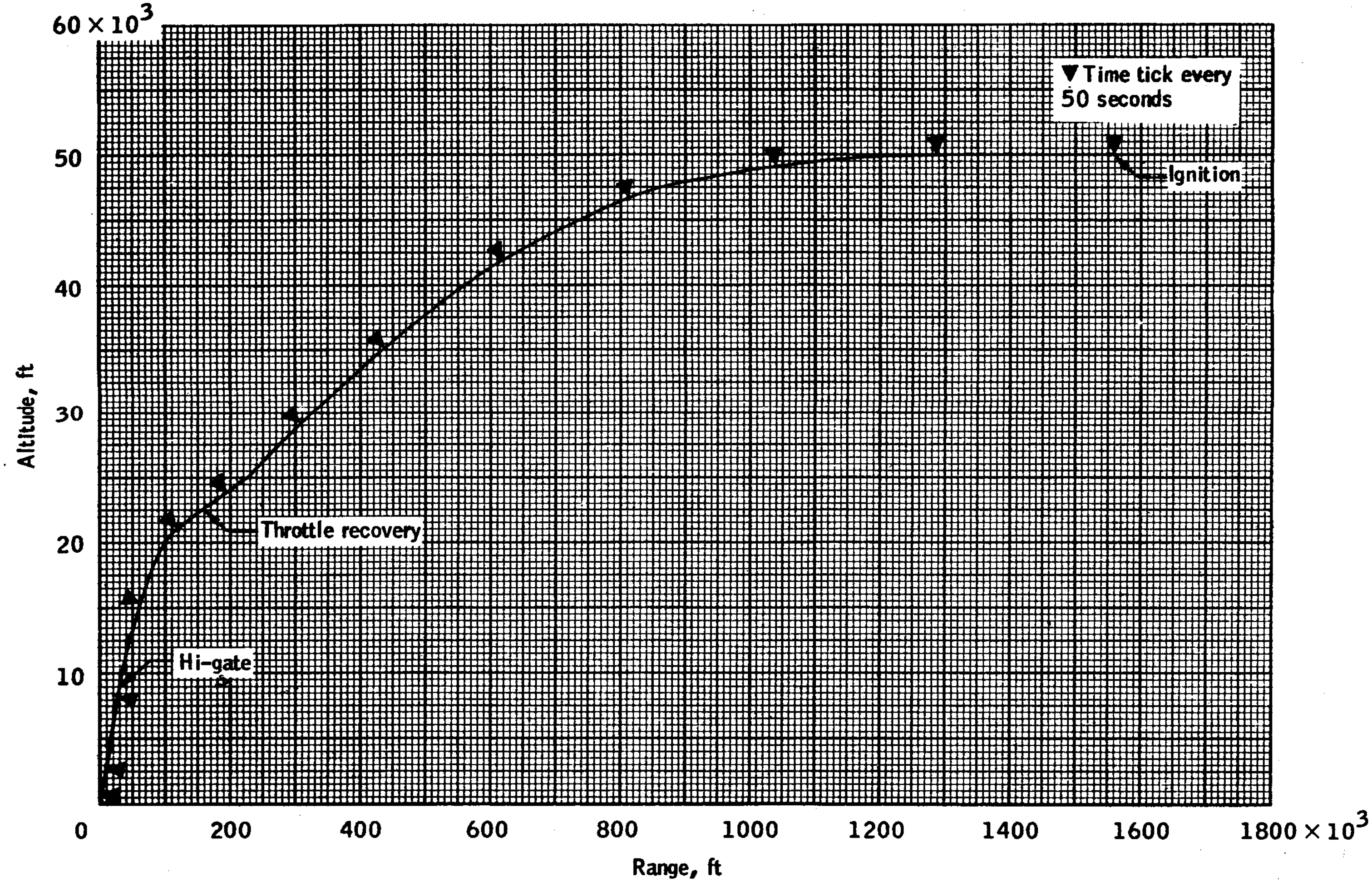


Figure 2. - Altitude-range profile for LM lunar descent trajectory.

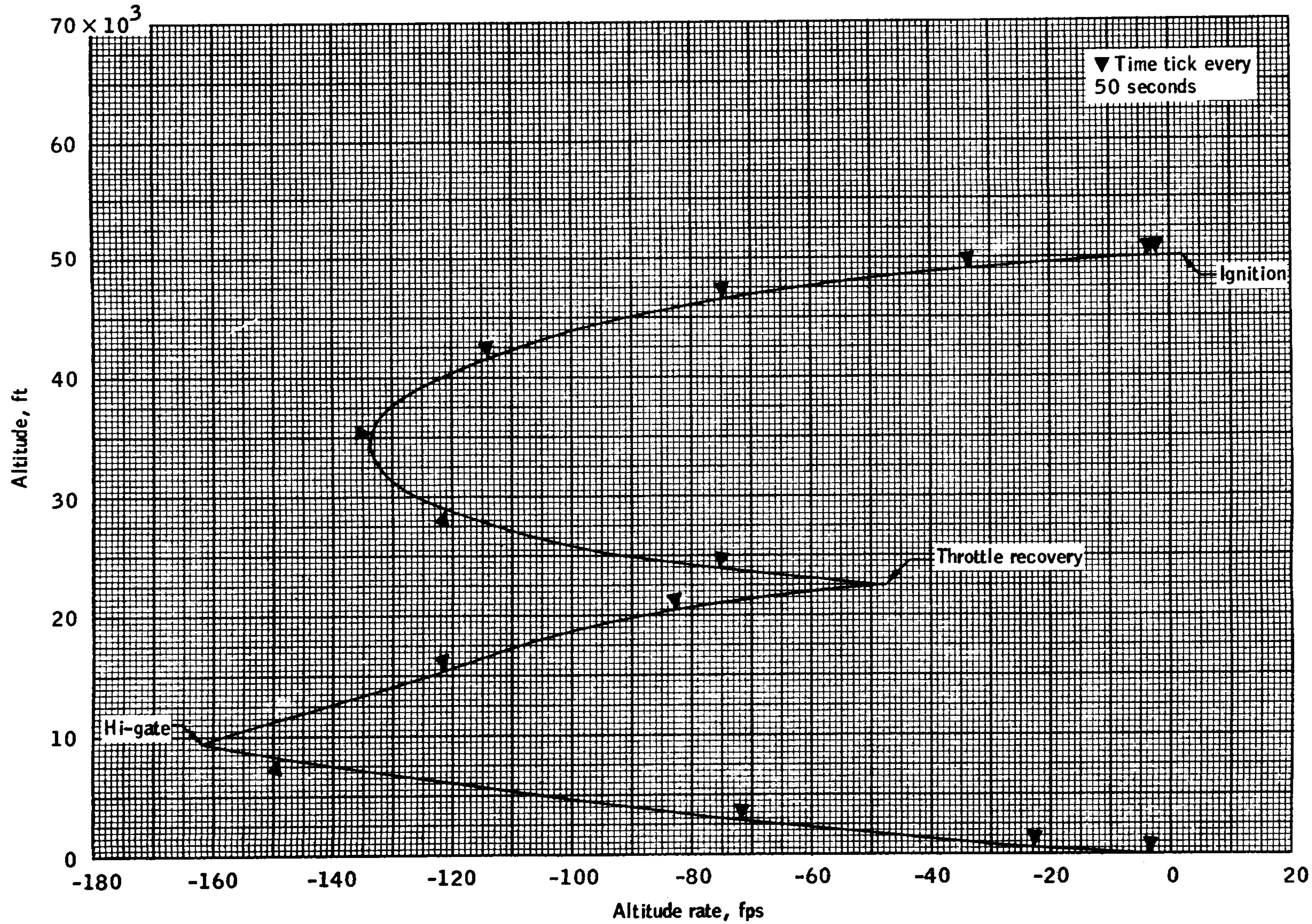


Figure 3. - Altitude-altitude rate profile for LM lunar descent trajectory.

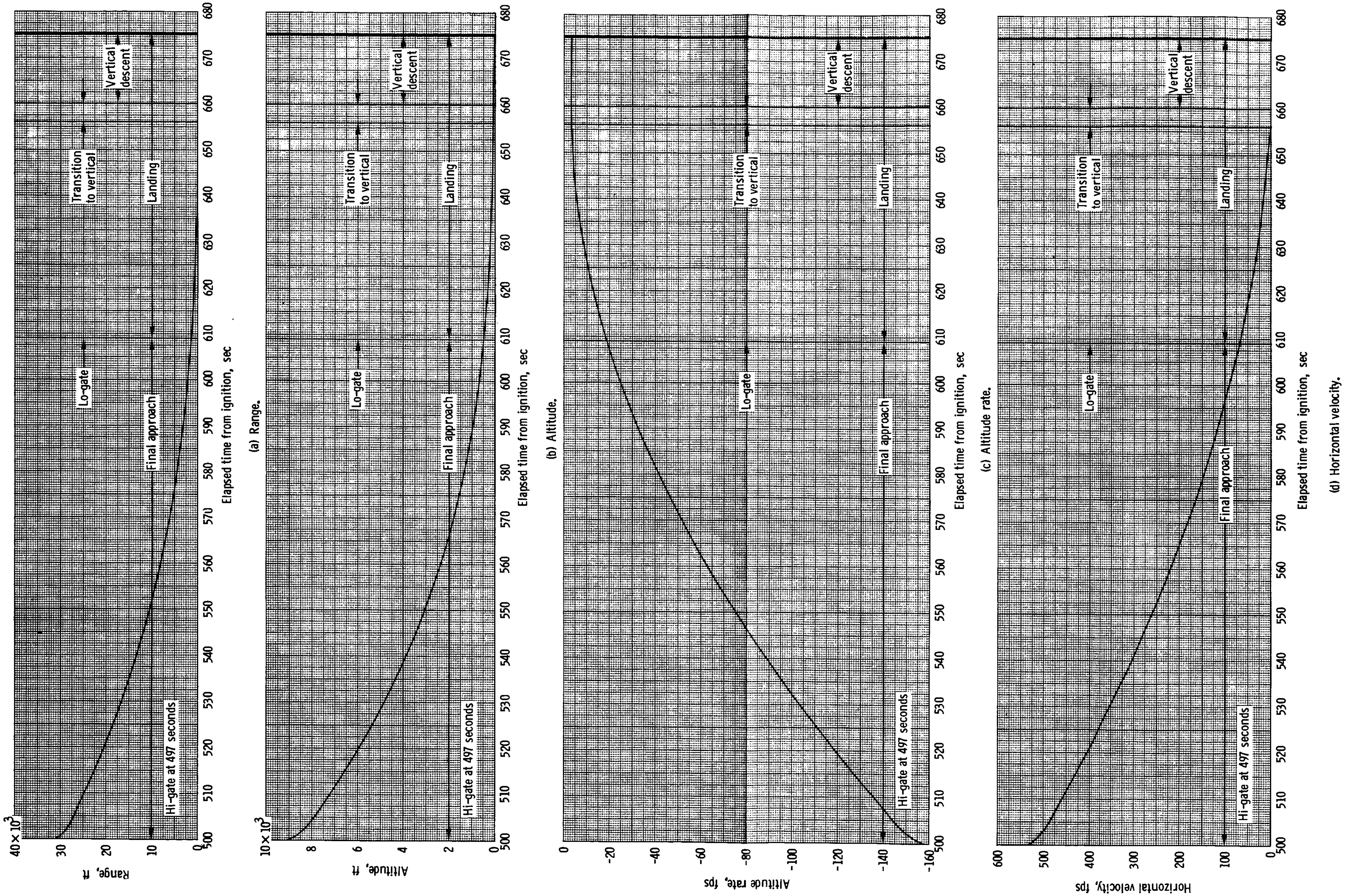


Figure 4. - Final approach and landing phases of LM lunar descent.

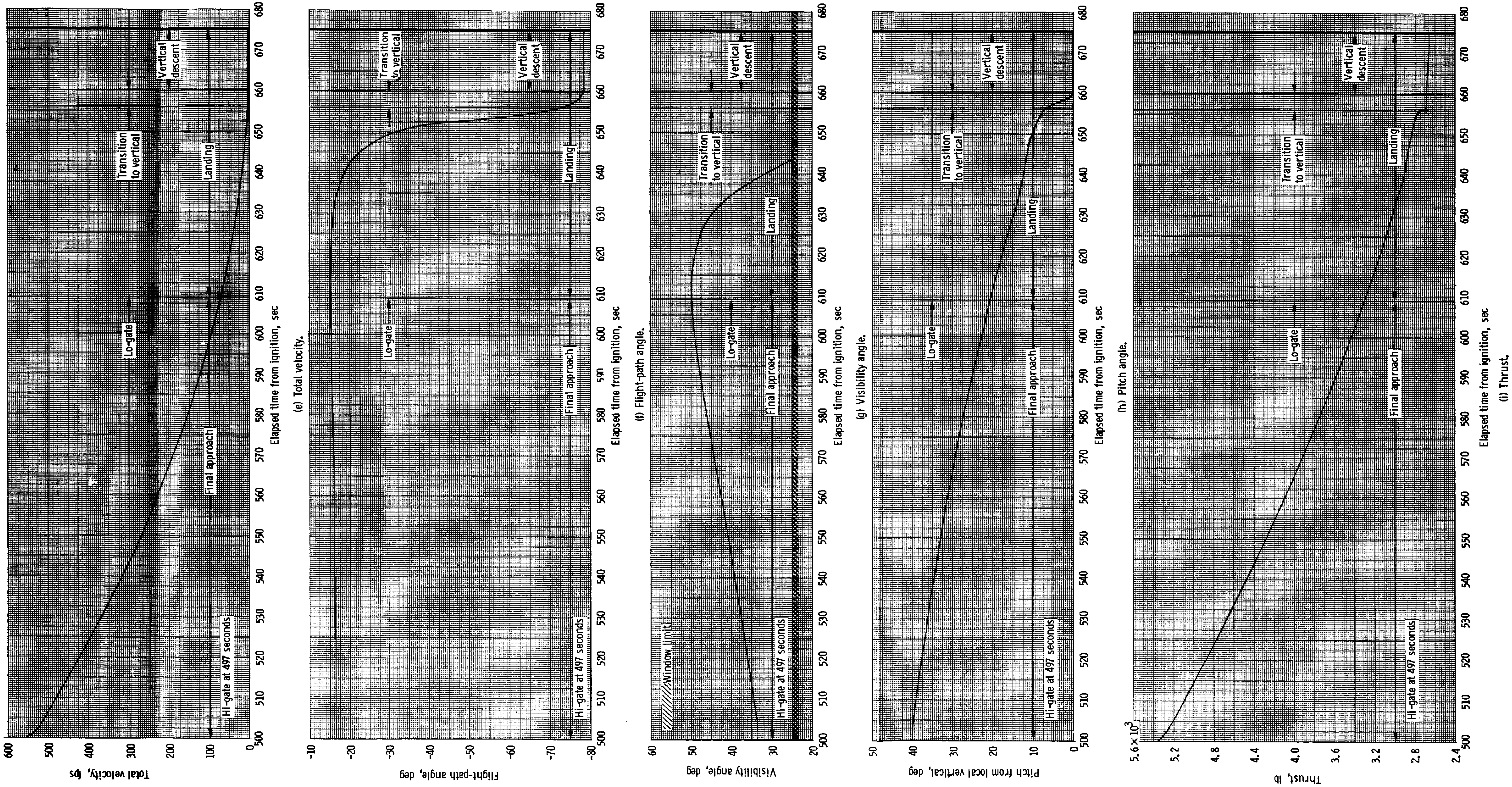


Figure 4. - Concluded.

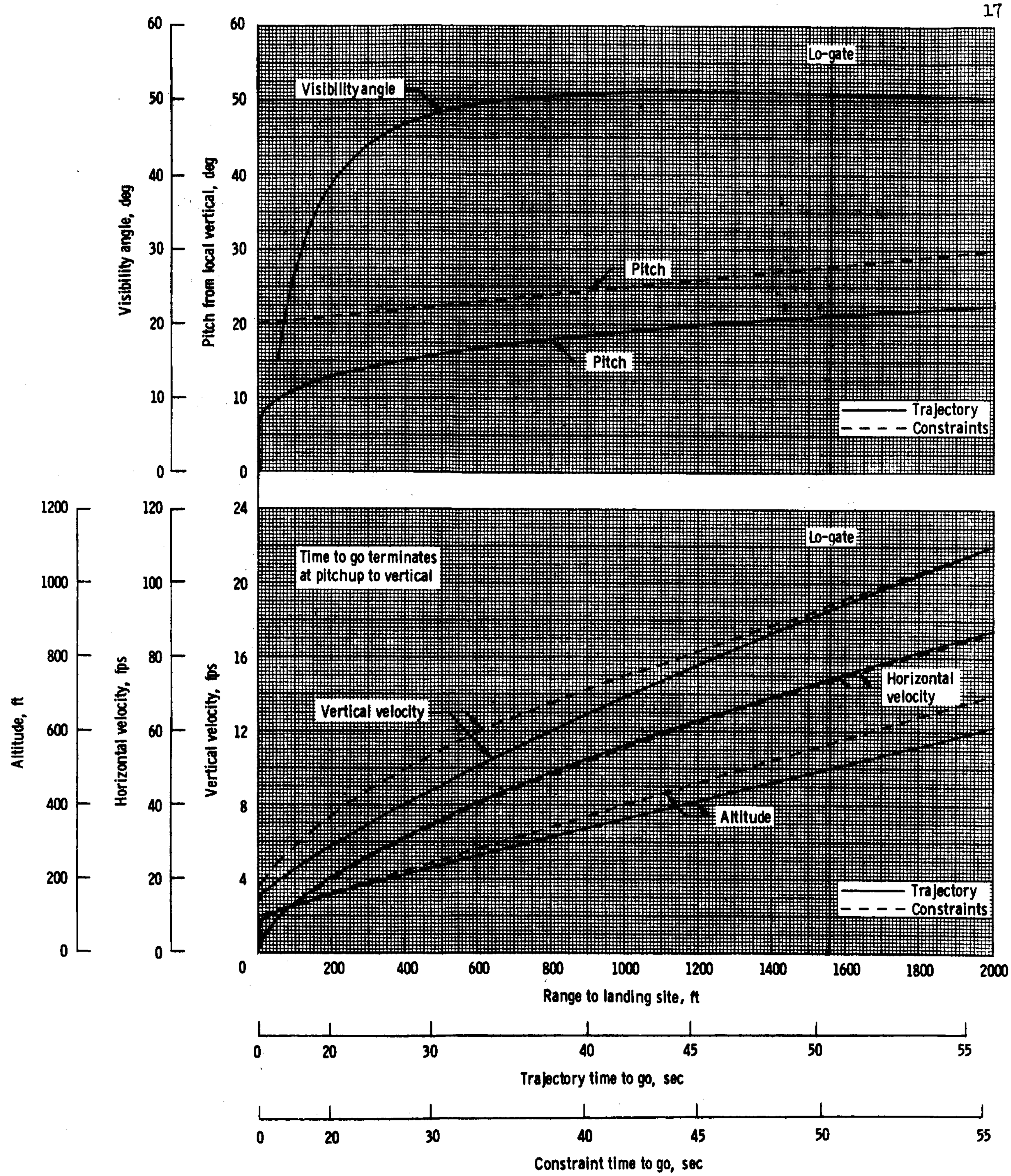


Figure 5. - Landing phase trajectory characteristics and constraints.

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